भारतीय मानक
Indian Standard

IS 17100 : 2019

भूमिगत कोयला गैसीकरण का पृथीकरण, निस्तारण एवं प्रभाग (यू सी जी)

Separation, Handling and Usage of Underground Coal Gasification (UCG)

ICS 75.020

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March 2019 **Price Group 6**

Methods and Equipments for Underground Coal Gasification and Coal Bed Methane Sectional Committee, MED 37

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Methods and Equipments for Underground Coal Gasification and Coal Bed Methane Sectional Committee had been approved by the Mechanical Engineering Division Council.

This standard provides for composition of syngas (synthetic gas) generated through UCG technique. This Standard is relevant for designers, producers, users and most importantly - the regulatory authorities, so as to identify and evaluate parameters which are of prime importance for separation, handling and usage of Underground Coal Gasification.

The composition of the Committee responsible for the formulation of this standard is given at Annex A.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

SEPARATION, HANDLING AND USAGE OF UNDERGROUND COAL GASIFICATION (UCG)

1 SCOPE

This standard covers;

a) Composition of syngas (synthetic gas) generated through UCG technique;
b) Impurities produced and purification requirement;
c) The applicable processing techniques; and
d) Potential end usages of the syngas.

2 TYPICAL SYNGAS COMPOSITION

2.1 Underground coal gasification yields the following main components:

a) Hydrogen (H_2),
b) Carbon monoxide (CO),
c) Carbon dioxide (CO_2),
d) Methane (CH_4),
e) Nitrogen (N_2), and
f) Water vapour (H_2O).

2.2 In addition, a range of minor components is also produced (depending largely on the trace elements and compounds present in the feed coal/lignite coal):

a) Nitrogen compounds,
b) Sulphur compounds,
c) Alkali,
d) Heavy metals,
e) Organometallic species, and
f) Various hydrocarbons resulting from pyrolysis reactions which occur in the absence of oxygen.

2.3 The composition of raw syngas from a UCG operation is broadly comparable with that obtained from surface gasification, conducted at low temperatures. When gasification occurs at lower temperatures, it is observed that higher concentrations of methane and carbon dioxide are generated and since UCG operation is at lower temperatures, it is expected that UCG syngas will be higher in these species than syngas from conventional surface gasification.

2.4 The oxyblown fluidized bed gasification generates higher concentration of carbon dioxide (CO_2) than carbon monoxide (CO) and hydrogen (H_2). High temperature surface gasification whether carried out in entrained flow or slagging gasifiers, has significantly higher carbon monoxide (CO) content and less carbon dioxide (CO_2) and methane. Syngas resulting from high temperature gasification is easier to process in downstream equipment.

3 SYNGAS PURIFICATION AND TREATMENT

3.1 Syngas Purification Requirements

Raw syngas from coal gasification contains many undesirable components including acid gases, heavy metals, nitrogen compounds and halides. The required level of treatment and optimal technologies will vary according to the ultimate disposition of the syngas.

There are two major consumption pathways for syngas:

a) Combustion for heat or power generation, and
b) Catalytic processes for production of chemicals and liquid fuels.

3.1.1 The processes used for purification are similar, the difference being the extent of syngas purification required, depending on the end use of the gas. Requirements for combustion and power generation are aimed at achieving regulatory emission requirements and to protect the equipment such as boilers and gas turbines. Requirements for chemicals and fuels are generally more stringent in order to avoid damage to the catalyst which may impact upon its efficiency, life, activity or conversion.

3.1.2 Some of the technologies employed for removing acid gas contaminants such as sulphur may also readily be used for bulk removal of carbon dioxide. Some processes (such as ammonia and methanol production) require removal or reduction of the carbon dioxide in syngas. Integrated Gasification and Combined Cycle power generation (IGCC) can also be adapted for removal of carbon dioxide (CO_2).

3.1.3 Syngas applications where a concentrated stream of carbon dioxide is produced may be particularly suited to carbon capture and storage (CCS), depending on availability of a sales outlet or storage sink (such as geological or biological sequestration). Although the commercial viability and long-term integrity of geo sequestration is yet to be established, the combination of gasification and CCS is of growing interest as it offers the potential for significant reductions in atmospheric greenhouse gas emissions when compared with conventional coal fired power generation.

The following sections outline syngas treatment requirements according to end use.

3.2 Power Generation

3.2.1 The extent of syngas clean-up for Gas turbine generator use will be largely driven by the emission regulations of the regulatory body holding jurisdiction over the facility site and the fuel specifications of the gas turbine supplier. These requirements typically address permissible levels of sulphur, oxides of nitrogen, and particulates and present no-special difficulties for UCG syngas.

3.2.2 Raw syngas is corrosive and in order to reduce the need for expensive corrosion resistant alloys will generally require some level of treatment including means to avoid condensation before it can be economically transported via pipeline.

3.3 Gas to Liquids Processes

3.3.1 *Fischer-Tropsch Synthesis*

The feed gas specifications for Liquid hydrocarbon synthesis via the Fischer Tropsch (FT) pathway are extremely stringent due to the sensitivity of the reaction catalyst. In particular, sulphur compounds and metals should be removed to very low levels. In practice, requirements vary according to process, catalyst, and licensor, and are subject to economic trace offs and so it is not possible to provide a single and universal specification. However, a typical FT feed gas specification is given in Table 1.

3.3.2 *In Addition*

a) High concentrations of inert components will result in lower yields due to purging requirements; and

b) The hydrogen (H_2) to carbon monoxide (CO) ratio requirement of the syngas varies from about 1.3 to 3 depending on the GTL technology employed.

3.4 Methanol to Gasoline (MTG)

The methanol to gasoline pathway also employs catalytic processes that require similar feed gas specifications and therefore similar syngas purification and processing to the GTL pathway. The optimum hydrogen (H_2) to carbon monoxide (CO) ratio for methanol production is typically close to 2, depending on carbon dioxide (CO_2) content.

3.5 Syngas Purification Technology

3.5.1 *Particulates*

The particulates present in the raw syngas can be removed using a variety of methods depending on the syngas end use.

3.5.2 *Wet Scrubbing*

Hot syngas is cooled and then scrubbed in a tower or wet venturi scrubber, removing particulates as well as a portion of highly water-soluble contaminants such as chlorides and nitrogen compounds. The gas can be cooled either in a waste heat boiler to produce high pressure steam, or by direct water contact.

3.5.3 *Simple Quenching*

In a similar process to wet scrubbing the hot syngas can be quenched with water to below the dew point. The particulates are then removed from the condensate by filtration or other means.

3.5.4 *Candle Filtration*

Ceramic candle filtration can remove particulates in hot syngas and has been successfully used in power generation (IGCC) facilities.

Table 1 Typical Fischer-Tropsch Feed Gas Specifications

(*Clause* 3.3.1)

Sl No. (1)	Impurity (2)	Feed Concentration (3)
i)	Sulphur compounds	< 1 ppm volume
ii)	Nitrogen compounds	< 1 ppm volume
iii)	Halogen compounds	< 10 ppb volume
iv)	Alkaline metals	<10 ppb volume
v)	Solids(including shoot, ash and dust)	Total removal
vi)	Organic compound (tars including BTX[a])	Removed below dew points[b]
vii)	Class 2 organic compounds[c]	<1 ppm volume

[a] BTX (Benzene, Toluene, Xylene).

[b] Removal to a level at which no condensation will occur during FT compression.

[c] Class 2 tars comprise of phenol, pyridine, and thiophene.

3.6 Hydrocarbon and Water Condensate

After syngas has been cooled to its dew point, liquid hydrocarbons and water condensate will form and may be separated as liquid phases. The water will generally contain dissolved gases and ionic species including ammonia, chlorides and cyanides and after suitable treatment may be recycled within the process, or treated and discharged in accordance with local regulations. The hydrocarbon phase can be burned as fuel or processed further according to available dispositions.

3.7 Carbonyl Sulphide Hydrolysis

Carbonyl sulphide (COS) may be removed via hydro-desulphurisation in fixed catalyst beds in which COS is rapidly hydrolysed to carbon dioxide (CO_2) and hydrogen sulphide (H_2S) in the presence of steam.

The reaction involved in the removal of COS is:

$$COS + H_2O \rightarrow CO_2 + H_2S$$

Since the hydrolysis reaction produces the acid gas components carbon dioxide (CO_2) and hydrogen sulphide (H_2S), carbonyl sulphide (COS) removal is generally performed prior to acid gas removal.

3.8 Acid Gas Removal

Solvents are widely used for acid gas removal and fall into either the chemical, physical or mixed categories. The two major components generally targeted for removal are carbon dioxide (CO_2). and hydrogen sulphide (H_2S). However, depending on the acid gas source other species may be present in greater or lesser quantities including oxides of nitrogen and sulphur, cyanides, halides including hydrogen chloride, and other sulphur compounds such as mercaptans and thiophenes. The relative quantities of these impurities and downstream process requirements will influence selection of both the solvent and technology employed. A final selection will typically be made in conjunction with process licensors and solvent vendors.

3.9 Chemical Solvents

3.9.1 Aqueousamine solvents such as MDEA (methyl diethanolamine) are intimately contacted with raw syngas in a multi-stage absorber. The solvent stream rich in acid gas is regenerated by heating (usually with steam) and recycled to the absorber. These processes are suited to high flow and low-pressure applications, such as post combustion capture for power stations. They feature a lower electrical power demand but higher heat energy requirements than physical solvents.

3.9.2 MDEA is ineffective in removing COS because the two are unable to chemically bind, therefore, prior Carbonyl sulphide (COS) removal or catalytic conversion to hydrogen sulphide (H_2S) is required. MDEA may also be unsuitable if significant amounts of nitrogen oxides (NOx) are present as the reaction to nitric acid (HNO_3) with water can decompose the amine, and hydrogen chloride (HCl) if present can also de-active the amine.

3.10 Physical Solvents

3.10.1 The two most common physical solvents are methanol (as used in the Rectisol process) and glymes, or dialkyl ethers of polyethylene glycol (as used in the Selexol and Genosorb processes). Physical solvents are preferred for high selectivity of hydrogen sulphide (H_2S) removal relative to carbon dioxide (CO_2). Their performance is proportional to the system pressure allowing for high loadings at high acid gas partial pressures.

3.10.2 Physical solvents are particularly attractive for syngas applications because hydrocarbon co-absorption is minimal due to the typically low hydrocarbon concentration in syngas.

3.10.3 Rectisol can effectively remove hydrogen sulphide (H_2S), carbonyl sulphide (COS) and metal carbonyls. Selexol and Genorsorb are less effective in carbonyl sulphide (COS) removal and generally require prior catalytic conversion of carbonyl sulphide (COS) to hydrogen sulphide (H_2S).

3.10.4 Despite the high selectivity towards hydrogen sulphide (H_2S), carbon dioxide (CO_2) recovery is still possible using physical solvents. In the case of Selexol, two stages are used to remove firstly hydrogen sulphide (H_2S) and then carbon dioxide (CO_2) in the secondary stage. For carbon dioxide (CO_2) recovery using a Rectisol solvent a two-stage process is also employed. The selective removal of sulphur components occurs in the first stage followed by a dedicated carbon dioxide (CO_2) removal step.

3.11 Mixed Chemical/Physical Solvents

Both chemical and physical solvents can be combined to take advantage of the best features of each. The Sulfinol process combines the chemical solvent MDEA or DIPA (diisopropanolamine with another amine, Sulfolane (tetramethylene sulfone). This combination allows for higher solvent loadings at high acid gas partial pressures. Higher carbonyl sulphide (COS) removal can also be achieved when compared to pure amine chemical solvent.

3.12 Sulphur Recovery

3.12.1 The processes used for acid gas removal generally produce a tail gas stream containing a high concentration of H_2S. Sulphur recovery from H_2S is possible via a Sulphur Recovery Unit (SRU) utilising the claus process and its variants or the liquid redox LO-CAT process both producing elemental sulphur.

3.12.2 The LO-CAT process produces a less pure sulphur product than does Claus and requires re-melting to obtain saleable quality sulphur. However, LO-CAT is better suited to smaller capacity applications, the breakpoint being around 30 tonne/day of sulphur and can be integrated into the overall process. LO-CAT is also suited where the H_2S concentration is low, whereas clause units require a higher feed concentration

3.13 Trace Component Removal

3.13.1 Metals such as arsenic, mercury and metal carbonyls (nickel and iron in particular) can be present in raw syngas in trace concentration. These components have the potential to poison the catalyst used in processes such as Fischer Tropsch synthesis. In addition, metal carbonyls have the ability to decompose and plate out on the surface of gas turbine generator blades. Although they are removed to an extent in upstream purification units, the further removal of such contaminants represents the final syngas purification step for liquids and chemical synthesis.

3.13.2 Activated carbon impregnated with sulphur has been used extensively in the gas processing industry for removal of mercury. Mercury reacts with sulphur to form a solid which is then retained within the adsorbent bed. Other trace components such as arsenic and metal carbonyls may also be captured.

3.13.3 Regenerative adsorbents are also proven for mercury removal in the gas processing industry based on molecular sieves. Safe recovery can be achieved using conventional regeneration equipment and operation methods. In addition, dedicated adsorbents for the removal of metal carbonyls are an option in certain situations.

3.14 Syngas Composition Adjustment-Gas Shift Reaction

The water gas shift reaction converts carbon monoxide (CO) and steam addition to generate further hydrogen (H_2) and carbon dioxide (CO_2). This reaction is used to increase hydrogen (H_2) content, to 'decarbonise' the syngas by conversion to carbon dioxide (CO_2) which may be subsequently removed by acid gas treatment, and it provides a controllable means to achieve a desired hydrogen (H_2) to carbon monoxide (CO) ratio which is key for technologies that are ratio specific. Some typical requirements of hydrogen (H_2) to carbon monoxide (CO) ratio for various end uses are shown in Table 2.

3.15 UCG By-products-Uses and Waste Management

3.15.1 The impurities present in the syngas derived from underground coal gasification are dependent on the ultimate analysis of the coal resource. For example, if the coal has high sulphur content then higher amounts of sulphur containing species such as hydrogen sulphide and sulphur oxides will be present in the syngas.

3.15.2 The main issues far gasification relate to carbon dioxide (greenhouse gas emissions, corrosively) and hydrogen sulphide (toxicity, acid rain, corrosively and catalyst deactivation).

3.15.3 Sulphur recovered from the SRU will typically be sold as fertilizer or possibly for sulphuric acid manufacture.

3.15.4 Waste gas with useful calorific value will generally be burned as fuel. Other purge and waste gases are either sent to flare or otherwise destroyed. All gaseous emissions will be dealt with in accordance with local air quality regulations.

3.15.5 A very significant advantage of UCG is that solid wastes including ash and char largely remain underground and hence do not incur handling and disposal costs. Particulate dust/ash that reaches the surface with the syngas can be removed in the initial syngas treatment and could potentially be re injected into the well. The net volume of solid waste requiring disposal should be assessed during the pilot burn phase.

3.15.6 Contaminated process aqueous effluent from syngas treating may contain solvents, hydrocarbons, particulates and catalyst. This stream may be treated to acceptable standards using conventional waste treatment processes and re-used within the plant or disposed of according to local regulations.

Table 2 H_2 : CO Ratio for Various Syngas End Sages

(*Clause* 3.14)

Process	Requirements	
	H_2 : CO Ratio	**Comments**
Power Generation	—	Lower Heating Value requirement, *Max* H_2 specification, N_2 or Steam diluent required.
SNG	3-4 : 1	Depending on operating conditions
Methanol MTG	2-2.1 : 1	Based on the stoichiometric number. Correct concentration of CO_2 is essential.
Fischer-Tropsch	1-3 : 1	Desired ratio depends on the catalyst being used
Ammonia	n/a	Pure H_2.CO is not required and is a catalyst poison

4 UCG SYNGAS HANDLING

4.1 Handling of Toxic Product Gases and Condensates

4.1.1 *Toxic Effects of Syngas and Condensate*

UCG process involves in-situ conversion of solid un-mineable coal into syngas. Thus, solid fuel gets converted to gas which is essentially a mixture of carbon monoxide (CO), hydrogen (H_2), hydrogen cyanide (HCN), nitrogen oxides (NO), hydrogen sulphide (H_2S), phenols etc. Condensates obtained from heat exchanger mainly contain tar and phenolic compound. The impact of major compounds is described below.

4.1.2 *Carbon Monoxide (CO)*

a) This gas is a chemical asphyxiant causing acute symptoms rapidly at 1 000 ppm and above and in 1 h at about 500 ppm;

b) The symptoms are generally those of hypoxia. The intoxication is reversible but hypoxemia is sufficient to cause unconsciousness and may leave permanent damage. Susceptibility varies considerably, being increased by any condition predisposing to cellular hypoxia, especially of the central nervous system;

c) The hazards of chronic low-level exposure are not to be ignored. In particular there is some indication of cardiovascular effects;

d) Particulate concentration is measured in terms of:

   (1) TWA (Time weighted average) is the maximum concentration of particulate in air to which workers can be exposed without adverse health effect for a period of 8 h a day.

   (2) Ceiling limit refers to the concentration of a chemical or material that no person should be exposed to for any period of time to prevent ill effects or death;

e) The OSHA standard is a TWA (time weighted average) limit of 50 ppm; and

f) NIOSH (National Institute of Occupational Safety and Health) has recommended a 35 ppm TWA limit and a 200 ppm ceiling limit.

4.1.3 *Hydrogen Cyanide (HCN)*

a) This is found as a liquid or gas (boiling point 26° C);

b) It acts as a chemical asphyxiant by inhibiting a cellular respiratory enzyme;

c) Possible acute effects include immediate death at 270 ppm and death after 10 min at 181 ppm;

d) Exposure at 18 to 36 ppm is said to cause slight symptoms after several hours;

e) Chronic effects are those of moderate hypoxia, including symptoms such as weakness, vertigo, nausea, rapid pulse, headache, flushing of the face, and gastric distress. Also, skin penetration by the vapor can be dangerous;

f) The OSHA standard is a 10 ppm TWA limit; and

g) The NIOSH-recommended standard is a 5 ppm/10 min ceiling limit.

4.1.4 *Hydrogen Sulphide (H_2S)*

a) This gas is a dangerous acute poison at concentrations of about 100 ppm and up; it therefore calls for emergency protection where such concentrations might occur, such as in the immediate vicinity of hydrogen sulphide (H_2S) rich process streams. It affects the nervous system and induces respiratory failure.

b) Chronic low-level exposure may induce various symptoms of malaise.

c) The gas is a strong irritant of the eye and respiratory tract at about 100 ppm and above, and a slight irritant at 10 ppm.

d) The OSHA standard is a 20 ppm ceiling limit, 50 ppm/10 min peak limit.

e) NIOSH has recommended a 10 ppm/10 min ceiling limit and continuous monitoring in areas where a concentration of 50 ppm (70 mg/m^3) may occur, requiring evacuation.

4.1.5 *Nitrogen Oxides (NO)*

a) Nitrogen dioxide is generally the most conspicuous hazard. It is an irritant of insidious effect because it can penetrate the lung deeply without immediate severe discomfort and induce a delayed pulmonary edema, which may be fatal;

b) However, nitrogen oxides are likely to be produced only if there is high temperature combustion (coal fired steam plant or combustion of wastes) and even then, only in low concentrations;

c) The OSHA standard for nitrogen dioxide is a TWA limit of 5 ppm; and

d) NIOSH recommends a 1 ppm ceiling limit.

4.1.6 *Phenols ($-C_6H_5-OH$)*

a) These may be either solids or liquid mixtures of moderate to high boiling point.

b) Phenol and related aromatic hydroxy compounds can be absorbed through the skin and some (for example, phenol) are sufficiently volatile to be possible respiratory hazards; others (cresols) are less volatile and present an unlikely vapor hazard. Their toxic effect is primarily on the central nervous system and they are also strong irritants.

c) It is the latter property which is likely to be the more significant in coal conversion plants, in the enhancement of carcinogenicity through the presence of phenols in skin contamination by tars or oils or in inhaled particles.

d) The OSHA standard is a TWA limit of 5 ppm.

e) NIOSH has recommended a 20 mg/m^3 TWA limit and a 60 mg/m^3/15-min ceiling limit.

4.2 Control Methods

a) To prevent sudden breakthroughs from the boreholes the heads of the wells are provided with the covers, gate valves and nipples with taps, to be pressurized before the start of UCG process under the pressure 1.25-1.5 times higher than an air blast working pressure. A borehole head pressurizing is made together with pipe casing of the well before cement plug redrilling or on a special bed. A high pressure air pipeline is equipped by a back-flow valve and a gate valve.

b) Condensate formed while gas cooling is non-combustible. But because of chemical substances and compounds in condensate contents the explosion-hazard concentration of stream can be formed in reservoir air space while storage of condensate.

c) The persons without suitable breathing device and those who do not undergo safety rules training are not allowed to be in these zones.

d) Guidelines on the test, operation and storage of protective means should be displayed at working places.

e) At a gas hazardous area, there should be an emergency means for protection from gas. Its type and amount are specified in accordance with the number of workers, area remoteness and specific character of the activities performed.

f) Apart from industrial safety certification managers and specialists should pass knowledge assessment in regulations requirements in terms of population and territory protection from emergency situations, sanitation-and-epidemiological population security, environmental protection and labour safety.

g) In gas hazardous places display warning sign board should be available like: “Toxic Gas hazard” in the regional language along with Hindi and English.

h) Condensate formed as a result from gas cooling in heat exchanger should be collected and stored in tanks by means of pumps.

j) There is also provision of heating the condensate by steam while gasifier is in operation in the tanks to reduce its viscosity. When gasifier is not in operation, steam is to be arranged through an alternate means.

k) The tanks are located on the waterproof covered site and bund. The coating is provided to reduce the possibility of condensate seeping through the bund and preventing soil ground and underground water pollution.

m) To control possible leakages from the tank bottom there is an outside drainage pit in a base of each tank with an outlet pipeline going to the inspection tank.

n) Liquid in the inspection tank means an emergency situation: - leakage in tank bottom. The urgent steps should be taken to solve an emergency situation. To empty an emergency tank there should be provision of transfer of liquid to another tank.

p) Water-resistant floor of the site where storage tanks are located is considered at a slope towards drains.

q) There are outlets from water drains as steel pipes of 200 mm diameter with shut-off valve, meant for ground drainage from the site where storage tanks are located. In normal position shut-off valve is closed.

r) In case of condensate leakage from pipelines or from storage tanks, leakage is contained within the fencing (bunding) of the storage and with the help of an in-tank pump liquid is transferred to the storage tank.

s) A regular control over the state of water drains, pipe culverts and shut-off valves ensures safe maintenance of the reception enter for collecting, storage and shipping of condensate.

t) While operating circulating water supply system, a need of its blow-down may occur. Water carrying off from the circulating system blow-down is sent to the dump wells.

5 SYNGAS USES

Syngas represents an extremely useful intermediate that serves as feedstock for numerous processes including heat and power generation, production of transportation fuels and chemical synthesis.

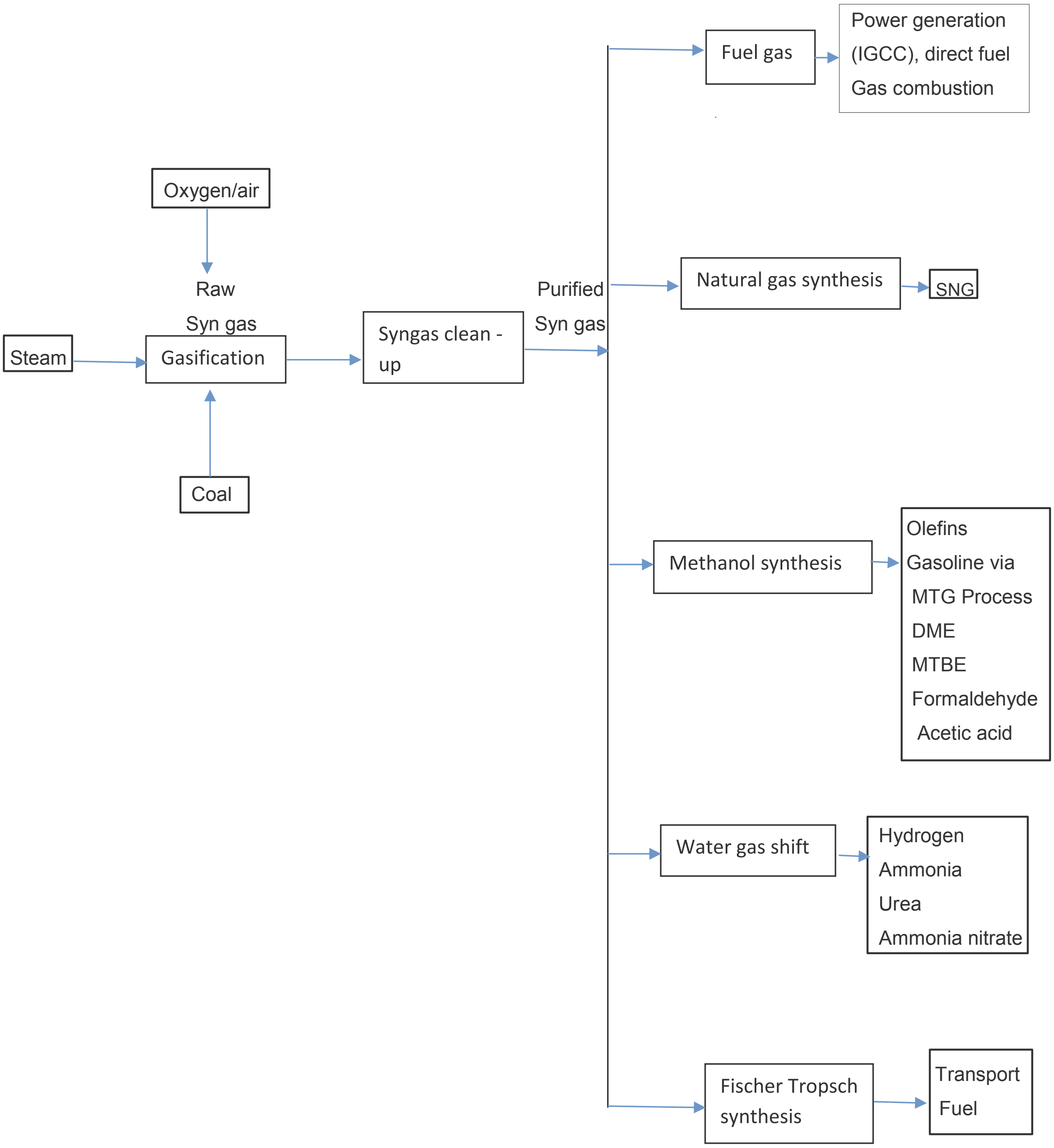
5.1 Heat and Power

Syngas can be burnt directly to produce heat, raise steam, or generate electricity; or it can be converted into synthetic natural gas (essentially fungible with natural gas) for transmission via pipeline to end users.

5.2 Raw or Purified Synthesis Gas

5.2.1 Supplying syngas in either its raw or purified form for combustion to generate heat or power is the most basic use of syngas. Purification of the synthesis gas will involve some of the techniques outlined in section discussed above.

5.2.2 Conversion of syngas to hydrogen using the water gas shift reaction can provide a clean low carbon



energy source provided the by-product carbon dioxide is captured and stored. Hydrogen is also a key feedstock in a range of processes in the petroleum and chemical industries (for example, hydrocracking, hydro treating, and ammonia production). However, Syngas and hydrogen are expensive to store in other than small quantities, and expensive also to transport over long distances. Therefore, it is expected that hydrogen and syngas consumers will generally be located adjacent or nearby to the UCG facility.

5.3 Electricity Generation

5.3.1 There are three main electricity-generation options: syngas combustion to produce steam for a steam turbine generator (STG), syngas combustion in a gas turbine generator (GTG), and combined cycle applications which employ a combination of GTG and STG to improve overall efficiency.

5.3.1.1 Simple cycle steam turbine power generation option is considered less attractive due to inherent efficiency losses of steam production.

5.3.1.2 A GTG system can operate in two different ways: as an Open Cycle (OC); or more efficient, Combined Cycle (CC), which has a higher capital cost. In OC, turbine exhaust gases are vented to the atmosphere, while CC incorporates sending the turbine exhaust gases through a heat recovery steam generator for additional power generation or production of utility steam or process heat.

5.3.2 Power can be generated adjacent to the UCG production facility as part of an integrated coal to power plant or alternatively syngas can be supplied to a third party generator via pipeline subject to safety and economic assessment. A considerable number of gas turbines have been fabricated for Integrated Gasification Combined Cycle (IGCC) applications with Low Calorific Value (LCV) syngas as a feedstock derived from a range of gasification raw materials.

5.3.3 Syngas used as a feedstock for power generation in a gas turbine generator has to meet environmental, Combustion and gas turbine requirements. Environmental requirements address nitrogen oxide (NOx) and sulphur oxide (SOx) emissions. SOx emissions can be reduced by an acid gas processing unit. NOx emission limits may be met by the use of flame combustors, dry low NOx (DLN) systems and flame temperature reduction methods. Selective Catalytic Reduction (SCR) may be used to further reduce NOx content; however, this process requires more thorough upstream sulphur removal to avoid the formation of undesirable by-products.

5.3.4 Carbon dioxide (CO_2) removal from raw syngas via water gas shift and acid gas removal can reduce greenhouse gas emissions and result in a H_2 rich syngas being fed to a GTG. However, the operation of gas turbine generators using high purity H_2 fuel is still under research. Gas turbines also impose certain specifications on minimum heating value, density, concentration of contaminants and absence of liquids. And finally, efficient gas turbine operation requires removal of substances (such as metal carbonyls) that can deposit on the turbine blades. All of these requirements can, in principle, be readily met using commercially available processes and technologies to treat the syngas produced via UCG.

5.4 Synthetic Natural Gas

The reactions to convert syngas to methane, as seen below, are exothermic reactions and the feed temperature to each reactor is between 250°C and 400°C with hot effluent exiting the reactor as high as 730°C. The effluent is then quenched to achieve the desired inlet temperature for the next reactor.

$$CO + 3H_2 \rightarrow CH_4 + H_2O + Heat$$
$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O + Heat$$
$$CO + H_2O \rightarrow CO_2 + H_2$$

Methanation process of Haldor topsoe called TREMP™ is the technique usually used for conversion of SNG as shown in Table 3. A near stoichiometric blend of H_2, CO and CO_2 is used and sent to a set of reactors.

5.5 Transport Fuels

Syngas may be converted to liquid transport fuels such as gasoline (via Methanol to Gasoline technology), and diesel (via Fischer-Tropsch synthesis).

5.6 Methanol to Gasoline (MTG)

5.6.1 Methanol is synthesised catalytically at temperatures of 200 to 250°C and pressures of 40 to 70 bar via two methanol producing reactions and the water gas shift reaction. The reactions are given by Twigg as:

$$CO + 2H_2 \rightarrow CH_3OH + Heat$$
$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O + Heat$$
$$CO + H_2O \rightarrow CO_2 + H_2 + Heat$$

The subsequent conversion of methanol to hydrocarbons occurs in two steps, the first of which involves dehydration of a portion of the methanol to DME over an alumina catalyst as follows:

$$2\ CH_3OH \rightarrow CH_3OCH_3 + H_2O$$

5.6.2 The next step involves oligomerisation of the DME/methanol mixture into gasoline over a shape-selective zeolite catalyst. The reaction products contain

Table 3 Typical Gas Composition and Heating Value for Substitute Natural Gas Produced by the TREMP™ Process

(*Clause* 5.4)

Sl No.	Component	Mole Percent
(1)	(2)	(3)
i)	Methane	94 - 98
ii)	Carbon dioxide	0.2 - 2
iii)	Hydrogen	0.5 - 2
iv)	Carbon monoxide	< 100 ppm
v)	Nitrogen + argon	2 - 3
vi)	Higher heating value, KJ/Nm^3	37,380 - 38,370

over 85 percent (dry basis) hydrocarbon products of C5 and higher. After cooling, the hydrocarbon phase is separated from the un-reacted feed gas and produced water and purified by simple distillation.

5.6.3 Gasoline produced by this process is of high quality, almost free of sulphur, and containing lower levels of olefins and benzene than conventionally refined gasoline. MTG makes gasoline of 92 octane so in some cases blending may be required to meet higher pool octane requirements.

5.6.4 The production of gasoline via MTG has the significant advantage of providing an easily stored intermediate product (methanol), which improves the overall reliability of the process; since in the event of a problem in either the syngas or methanol unit, the other section may continue to operate using the methanol storage inventory as a buffer.

5.6.5 Methanol is a widely traded chemical product and with the addition of a methanol purification section the MTG plant may produce both gasoline and chemical grade methanol, depending on market demand and relative prices.

5.6.6 Oxygen blown UCG derived syngas will be preferred for methanol production to reduce the level of inert gases in the synthesis loop, which otherwise would incur higher purge rates and lower per-pass reactor conversions. However, the co-generation of both power and methanol using air blown UCG syngas may be an option in a methanol and power co-production facility.

5.7 Fischer-Tropsch Liquid Synthesis

5.7.1 In the 1920's German researches Franz Fischer and Hans Tropsch of the Kaiser Wilhelm Institute developed the original process of the synthesis of liquid hydrocarbons from syngas. The simplified Fischer-Tropsch (FT) reaction is shown below and it consists of chemical reaction of the carbon monoxide and hydrogen present in syngas:

$$CO + 2H_2 \rightarrow -(CH_2)- + H_2O + Heat$$

5.7.2 Materials produced by the FT process range from light gases to heavy waxes. Light gases can be used as a fuel within the production facility or to produce hydrogen. Waxes can be either directly sold or further treated to produce saleable transport fuels including synthetic diesel fuel, synthetic naphtha and synthetic kerosene. The quality of the synthetic diesel is higher compared with conventionally refined diesel derived from petroleum sources - it has high cetane, low sulphur and aromatics, and superior cold flow characteristics.

5.7.3 Synthetic naphtha is highly paraffinic, with a low content of naphthenes and aromatics, and a very low content of sulphur. It has poor octane and needs to be upgraded for blending into gasoline pools but is an excellent chemical feedstock for olefin production.

5.7.4 The synthetic kerosene fraction is an excellent blending component for aviation turbine fuels due to the absence of aromatics and its very high smoke point.

5.8 Chemicals and Polymers

Syngas can be used to produce ammonia and methanol which in turn are the basic building blocks for a wide range of other chemicals including fertilisers, explosives, plastics, and oxygenates.

5.8.1 *Ammonia*

Ammonia is the basic building block for the world's nitrogen industry and is a major chemical feedstock for the production of fertilisers and explosives. The technology used today is still based directly on the original synthesis route developed by Haber and Bosch.

Ammonia synthesis via the Haber process is obtained by reacting hydrogen obtained from the syngas and nitrogen from either air or from an air separation unit using an iron oxide catalyst.

$$N_2 + 3H_2 \quad => \quad 2NH_3 + Heat$$

The hydrogen to nitrogen ratio is one of the critical parameters for design and operation of the ammonia synthesis loop. In practice a ratio in the range of 2.2-3 hydrogen to 1 nitrogen gives the most efficient operating point within the limits imposed by overall optimisation.

5.8.2 *Methanol*

5.8.2.1 The methanol synthesis reactions have already been presented in Section above. The process to synthesise methanol from carbon monoxide and hydrogen was introduced in 1923 some ten years after the Haber process. This process was the outcome of extensive research of the hydrogenation of carbon monoxide which showed that depending on process conditions and selection of catalysts, hydrogen and carbon monoxide could react at pressures between 100 and 300 bar to produce chemicals ranging from methanol to higher alcohols, hydrocarbons and other oxygenated compounds.

5.8.2.2 The suitability of the feed syngas composition for methanol synthesis can be determined by its Stoichiometric Number (SN) which is given by the following quotient of mole fractions;

$$SN = \frac{H_2\text{-}CO_2}{CO + CO_2}$$

5.8.2.3 A stoichiometric number in the range on 2-2.1 is generally regarded as optimum. In addition, a CO_2 content between 2.5 percent and 3.5 percent is desirable, up to a maximum of about 8 percent. A small amount of carbon dioxide is desirable to provide a reactive feed mixture, whereas high levels may affect catalyst life and will produce greater quantities of water in the reactor effluent, which is expensive to remove.

5.8.2.4 During passage through the reactor only a portion of the feed syngas is converted to methanol. Un-reacted syngas is separated from the raw liquid methanol product and recycled back to the reactor. This allows for greater conversion efficiency and a smaller reactor size. However, inert components which do not participate in the reaction accumulate over time and must be purged from the synthesis loop.

5.8.2.5 Methanol must be distilled to remove higher alcohols (fuel oils) and water to comply with chemical grade specifications. The distillation is energy intensive and requires at least two sizable columns. Methanol destined for gasoline production via MTG does not need to be distilled.

5.9 Other Chemicals

As mentioned previously ammonia is used to produce fertilisers and explosives, including:-

a) Nitric acid and ammonium nitrate;
b) Urea Methanol is similarly be used to produce a wide range of chemical products, including Olefins and polyolefin for plastics;
c) Dimethyl ether (DME) which is used as an aerosol propellant and fuel;
d) Methyl tert-butyl ether (MTBE), a fuel additive;
e) Formaldehyde, a precursor to products like adhesives and sanitary paper;
f) Acetic acid, for food additives, glue and de-scaling agents, and; and
g) Oxo-alcohols, for solvents, detergents and plasticisers.

ANNEX A

(*Foreword*)

Organization(s)	*Representative(s)*
Oil And Natural Gas	Shri Rajeev Kumar Singhal (***Chairman***) Shri O. N. Gyani (*Alternate* I) Shri A. K. Paswan (*Alternate* II) Ms Vishakha Singh (*Alternate* III) Shri Khalequz Zaman (*Alternate* IV) Shri Shakeel Ahmed (*Alternate* V) Shri S Marandi (*Alternate* VI)
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Central Mechanical Engineering Research Institute (CMERI)	Dr P. K. Chaterjee Dr M. K. Karmakar (*Alternate*)
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Great Eastern Energy Corporation Limited (GEECL)	Shri Anoop Gupta Shri Priyaranjan Patra (*Alternate*)
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Neyveli Lignite Coporation (NLC)	Shri K. Alagar Shri M. Krishnan (*Alternate*)
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In Personal Capacity	Shri Rudra Pratap Singh

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This Indian Standard has been developed from Doc No.: MED 37 (13133).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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Published by BIS, New Delhi